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(54) APPARATUS FOR DETECTING TROUBLE WITH SOLENOID-OPERATED DEVICE

(57) An apparatus for determining faults of an electromagnetic coil actuator that includes two current paths having of two pairs of series switches(10,20,30,40) and an electromagnetic coil(1) connected between the intermediates nodes(2,4) of the pairs. The existence of faults of an electromagnetic coil actuator is decided based both on the state of operation of the switch pair and on the magnitude of the voltage signal corresponding to the sum of a first voltage signal(V_P) and a second voltage signal(V_N) corresponding, respectively, to potentials at the intermediate nodes(2,4).

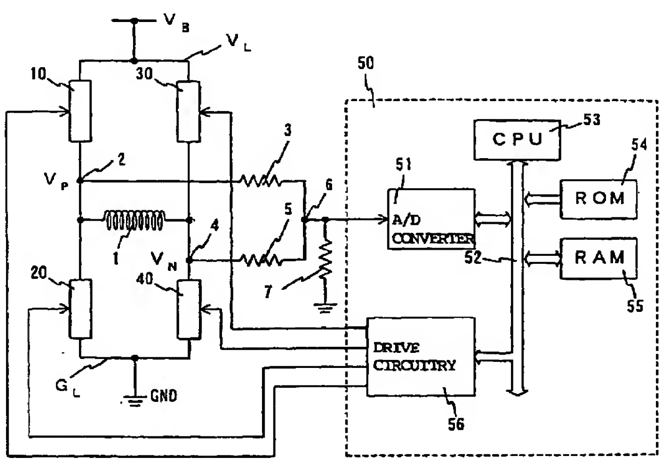

FIG.2

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Description

Field of the Invention

[0001] The present invention relates to an apparatus for determining faults of an electromagnetic coil actuator having electromagnetic coils.

Background Art

[0002] The apparatus shown in Fig.1 is known as an apparatus for determining faults of an electromagnetic coil actuator used for changing the direction of a current supplied to an electromagnetic coil into the forward or reverse direction. This apparatus determines a fault due to a short circuit between the connecting line and the ground wire in an electromagnetic coil actuator (hereinafter designated as "line-to-ground fault") and a fault due to a short circuit between the connecting line and the power supply line in an electromagnetic coil actuator (hereinafter designated as "supply-to-line fault") in order to protect the electromagnetic coil actuator and to prevent current leakage outside of the actuator.

[0003] A power supply line of the power unit (not shown) is connected to FETs 10 and 30, and switching elements, via resistors 62 and 63. An operational amplification element 61 is connected to the connecting line between the resistor 62 and the FET 10, and the connecting line between the resistor 63 and the FET 30. In addition, the FETs 10 and 30 are connected to FETs 20 and 40, respectively. Both ends of an electromagnetic coil 1 are connected to the connecting line between the FET 10 and FET 20, and the connecting line between the FET 30 and FET 40, respectively. The FET 20 and FET 40 are connected to a ground via a resistor 72 and connected to an operational amplification element 71.

[0004] Switching operation of the FETs 10, 20, 30, and 40 controls the direction of the current and stops the power supply from the power supply to the electromagnetic coil 1. Moreover, the operational amplification element 61 and resistors 62 and 63 constitute a supply current detecting circuit 60. The supply current detecting circuit 60 detects the value of current supplied to the FETs 10 and 30 based on a voltage drop produced through the resistors 62 and 63. Furthermore, the operational amplification element 71 and the resistor 72 constitute an over-current detecting circuit 70. The over-current detecting circuit 70 detects the value of current passing through the FETs 20 and 40 based on a voltage drop produced through the resistor 72.

[0005] However, the apparatus shown in Fig.1 required two detecting circuits which are the supply current detecting circuit 60 and the over-current detecting circuit 70. The apparatus is inconvenient because a determining program for determining a fault of the electromagnetic coil actuator based on the value of current detected by the detecting circuits becomes complicated. Additionally, heat generated from the resistors 62, 63, and 72 which were provided for current detection caused the temperature of a CPU, FETs and the like, provided near these resistors, to increase and caused these elements to be subject to malfunctioning. Therefore, this raised a problem in that a current could not be supplied properly to the electromagnetic coil. Furthermore, since the signal supplied to an operational amplification element of a current detecting circuit is a faint signal, the signal is subject to noise. This also raised a problem in that a fault of the electromagnetic coil actuator could be determined in a wrong way based upon the occurrence of noise.

[0006] In view of the foregoing, the object of the present invention is to provide an apparatus for determining faults of an electromagnetic coil actuator that reduces cost, supplies current properly to an electromagnetic coil, and determines desirably a fault of an electromagnetic coil actuator.

Summary and Objects of the invention

[0007] An apparatus for determining faults of an electromagnetic coil actuator, according to the present invention, is an apparatus having two current paths each of which comprises a pair of switches connected in series to each other, an electromagnetic coil connected in between connection points of each pair of the pair of switches, a drive circuit for selectively driving the switches, and power supply means for applying voltage to both ends of the both current paths via a power supply line and ground line, which comprises voltage detecting means for detecting an electric potential at respective connection points of the pair and for generating a first voltage signal and a second voltage signal according to the electric potential; adding means for generating a summing voltage signal according to a value obtained by adding a value of the first voltage signal to a value of the second voltage signal; and faults determining means for determining faults of the electromagnetic coil actuator based on operational conditions of the pairs of switches and the value of the summing voltage signal.

[0008] That is, according to the features of the present invention, the cost of the apparatus can be reduced and current can be appropriately supplied to a power supply coil and a fault of an electromagnetic coil actuator can be determined precisely.

Brief Description of the Drawings

[0009]

Fig.1 is a circuit diagram showing a background art apparatus for determining faults of an electromagnetic coil actuator.

Fig.2 is a circuit diagram showing an apparatus for determining faults of an electromagnetic coil actua-

tor according to the present invention.

Fig.3 is a circuit diagram showing the operation of an electromagnetic coil actuator in an "on" mode.

Fig.4 is a circuit diagram showing the operation of an electromagnetic coil actuator in an "off" mode.

Fig. 5 is a flowchart showing a subroutine for determining a line-to-ground fault.

Fig. 6 is a flowchart showing a subroutine for determining a supply-to-line fault.

Fig.7 is a time chart showing the variation in voltage and current in an experiment where a line-to-ground fault is produced.

Fig.8 is a time chart showing the variation in voltage and current in an experiment where a supply-to-line fault is produced.

Detailed Description of the Preferred Embodiment

[0010] The embodiments of the present invention will be explained below with reference to the drawings.

[0011] Fig.2 shows an apparatus for determining faults of an electromagnetic coil actuator, according to the present invention. The components corresponding to those shown in Fig. 1 are given the same symbols.

[0012] Supply voltage V_B is supplied to the switching elements, for example, to the FETs 10 and 30 via a power supply line V_L. The switching elements 10 and 30 are connected, for example, to the FETs 20 and 40, respectively, and the FETs 20 and 40 are connected to ground GND via a ground line G_L. An end of the electromagnetic coil 1 is connected to the connecting line between the switching element 10 and the switching element 20, and the other to the connecting line between the switching element 30 and the switching element 40, respectively. In addition, a resistor 3 is connected to a connection point 2 of the connecting line between the switching element 10 and the switching element 20, and a resistor 5 is connected to a connection point 4 of the connecting line between the switching element 30 and the switching element 40. It is to be understood that a voltage value at the connection point 2 is hereinafter called V_P and a voltage value at the connection point 4 is called V_N. The resistors 3 and 5 are connected to a connection point 6 and then connected to an A/D converter 51 provided in an engine control unit 50 via a resistor 7 which is used for setting voltage to a predetermined voltage value. In the case where the resistors 3 and 5 are given the same resistance value, the voltage value at the connection point 6 takes a value corresponding to the sum of V_P and V_N. The A/D converter 51 converts a supplied signal to a digital signal and then supplies the signal to an I/O bus 52. The I/O bus 52 is configured so as to input a data signal or an address signal to and output the same from a CPU 53. In addition, the I/O bus 52 is connected with a ROM 54, a RAM 55, and drive circuitry 56 for driving switching elements 10, 20, 30, and 40. The drive circuitry 56 is connected to the control signal input terminals of the switching elements 10, 20, 30, and 40. Moreover, the ROM 54 has a program stored therein which is used for determining a fault of an electromagnetic coil actuator in accordance with the flowchart to be explained in Fig.5 and Fig.6.

[0013] As mentioned above, the switching elements 10 and 20 or the switching elements 30 and 40, and the connecting lines thereof constitute current paths. The switching elements 10, 20, 30, and 40, and the electromagnetic coil 1 constitute the electromagnetic coil actuator. The drive circuitry 56 constitutes the drive circuit. The power supply (not shown) comprises the power supply means. The connecting line between the connection point 2 and the resistor 3, and the connecting line between the connection point 4 and the resistor 5 comprises the voltage detecting means. The resistors 3 and 5 comprises the adding means. The A/D converter 51, the I/O bus 52, the CPU 53, ROM 54, and RAM 55 comprises the faults determining means.

[0014] Hereinafter, it is to be understood that the state where the switching elements 10 and 30 are opened and the switching elements 20 and 40 are closed is called the "off" mode. In contrast, the state where the switching elements 20 and 30 are opened and the switching elements 10 and 40 are closed, or the switching elements 10 and 40 are opened and the switching elements 20 and 30 are closed is called the "on" mode. An explanation is to be given below of the state where the switching elements 20 and 30 are opened and the switching elements 10 and 40 are closed. In addition, the switching elements 10, 20, 30, and 40 are driven in response to a command signal generated by the aforementioned CPU 53 to switch between the "on" mode and the "off" mode. Furthermore, it is to be understood that the value of the input resistance of the A/D converter 51 is high enough to ignore the value of the current supplied to the A/D converter 51. Furthermore, it is to be understood that the resistors 12, 22, 32, and 42 to be mentioned later in Fig.3 and Fig.4 provide resistance included in the respective switching elements 10, 20, 30, and 40, for example, the "on" resistance and have the same value of resistance. Still furthermore, a fault due to a short circuit between the connecting line of the electromagnetic coil actuator and the GND is called the "line-to-ground fault", and a fault due to a short circuit between the connecting line of the electromagnetic coil actuator and the power supply line is called the "supply-to-line fault".

[0015] Fig.3 shows the operation of the electromagnetic coil actuator in the "on" mode. The components corresponding to those shown in Fig.2 are given the same symbols.

[0016] Under this condition, the supply current from the power supply is supplied to the electromagnetic coil 1 via an on/off switch 11 and a resistor 12 of the switching element 10, and thereafter flows into the GND via an on/off switch 41 and a resistor 42 of the switching element 40. At this time, V_P is lower than the supply volt-

age V_B by a voltage V_{12} through the resistor 12, whereas voltage V_N is higher than the ground voltage by a voltage V_{42} through the resistor 42. In a preferred condition of the electromagnetic coil actuator, the currents flowing through the resistors 12 and 42 have the same value, so that the voltages V_{12} and V_{42} through the respective resistors 12 and 42 are identical to each other and the sum of voltage V_P and voltage V_N is equal to the supply voltage V_B.

[0017] On the other hand, in cases where a current flows through the switching element 10 because of the line-to-ground fault, for example, the connecting line between the switching elements 10 and 20 is short-circuited to the GND, an increase in the current flowing through the resistor 12 of the switching element 10 causes the voltage V_{12} through the resistor 12 to increase and the sum of V_P and V_N becomes less than V_B. Therefore, it can be determined that a line-to-ground fault has occurred when the difference between the sum of V_P and V_N and the value V_B is greater than a predetermined value V_D. The predetermined value V_D has been determined experimentally in advance.

[0018] Fig.4 shows the operation of the electromagnetic coil actuator in the "off" mode. The components corresponding to those shown in Figs.2 and 3 are given the same symbols.

[0019] Upon switching from the "on" mode to the "off" mode, the inductance of the electromagnetic coil 1 causes a current to flow. This current flows through the circuit from the GND through a resistor 22 and the on/off switch 21 of the switching element 20, the electromagnetic coil 1, and the on/off switch 41 and the resistor 42 of the switching element 40 to the GND. At this time, V_P becomes lower than the ground potential by a voltage V_{22} through the resistor 22, whereas V_N becomes higher than the ground potential by a voltage V_{42} through the resistor 42. In a preferred condition of the electromagnetic coil actuator, the currents flowing through the resistors 22 and 42 have the same value, so that the absolute values of the voltages V_{22} and V_{42} through the respective resistors 22 and 42 are identical to each other and the sum of V_P and V_N is equal to 0.

[0020] On the other hand, in cases where a current flows through the switching element 40 because of the supply-to-line fault, for example, the connecting line between the switching elements 30 and 40 is short-circuited to the power supply line, an increase in the current flowing through the resistor 42 of the switching element 40 causes the voltage V_{42} through the resistor 42 to increase and the sum of V_P and V_N becomes greater than 0. Therefore, it can be determined that a supply-to-line fault has occurred when the sum of V_P and V_N is greater than a predetermined value V_U. The predetermined value V_U has been determined experimentally in advance.

[0021] It is assumed in the following that start-up processing such as initializing variables used in the CPU 53 have been completed and the electromagnetic coil actuator is performing a predetermined constant operation such as repeating the aforementioned "on" and "off" modes at intervals of a constant period.

[0022] Fig. 5 shows a subroutine for determining a line-to-ground fault.

[0023] First, it is determined whether or not the electromagnetic coil actuator is in an "on" mode (Step S11). If it has been determined that the actuator is not in an "on" mode, the subroutine is terminated immediately. On the other hand, if it has been determined that the actuator is in an "on" mode, V_P V_N, and V_B are detected (Step S12). Then, it is determined whether or not $V_B - (V_P + V_N)$ is greater than the predetermined value V_D (Step S13). If it has been determined that $V_B - (V_P + V_N)$ is equal to or less than V_D, the subroutine is terminated. On the other hand, if it has been determined that $V_B - (V_P + V_N)$ is greater than V_D, the electromagnetic coil actuator is determined to be at fault due to a line-to-ground fault. Then a line-to-ground fault processing is carried out, for example, the switching elements 10, 20, 30, and 40 are made to open to stop power supply to the electromagnetic coil actuator (Step S14), and then the subroutine is terminated. As mentioned above, a line-to-ground fault is determined at the time of an "on" mode.

[0024] Fig.6 shows a subroutine for determining a supply-to-line fault.

[0025] First, it is determined whether or not the electromagnetic coil actuator is in an "off" mode (Step S21). If it has been determined that the actuator is not in an "off" mode, the subroutine is terminated immediately. On the other hand, if it has been determined that the actuator is in an "off" mode, V_P and V_N are detected (Step S22). Then, it is determined whether or not $V_P + V_N$ is greater than the predetermined value V_U (Step S23). If it has been determined that $V_P + V_N$ is equal to or less than V_U, the subroutine is terminated. On the other hand, if it has been determined that $V_P + V_N$ is greater than V_U, the electromagnetic coil actuator is determined to be at fault due to a supply-to-line fault. Then a supply-to-line fault processing is carried out (Step S24) and the subroutine is terminated. As mentioned above, a supply-to-line fault is determined at the time of an "off" mode.

[0026] As mentioned above, a fault of the electromagnetic coil actuator can be determined by the sum of V_P and V_N without the need for determining by the respective V_P and V_N separately. For this reason, the apparatus explained in Fig. 2 can have fewer number of input terminals used for the A/D converter 51 and this allows the time for operation at the CPU 53 to be shortened.

[0027] Fig.7 shows a change in voltage and current in an experiment where a line-to-ground fault is allowed to occur.

[0028] It can be seen that the value of $V_P + V_N$ in an "on" mode is less than V_B when a current produced by a line-to-ground fault flows through the electromagnetic coil actuator while a cycle having an aforementioned

one "on" mode and one "off" mode is executed repeatedly at a time interval of 1ms. In this experimental example, if it is determined twice on a continual basis that $V_B - (V_P + V_N)$ is greater than the predetermined value V_D, a line-to-ground fault is determined to have occurred and then power supply to the electromagnetic coil actuator is stopped.

[0029] Fig. 8 shows a change in voltage and current in an experiment where a supply-to-line fault is allowed to occur.

[0030] As in the case of Fig.7, it can be seen that the value of $V_P + V_N$ in an "off" mode has become greater than ground potential when a current produced by a supply-to-line fault flows through the electromagnetic coil actuator while a cycle having one "on" mode and one "off" mode is executed repeatedly at a time interval of 1ms. If it is distinguished twice on a continual basis that $V_P + V_N$ is greater than the predetermined value V_U, a supply-to-line fault is determined to have occurred and then power supply to the electromagnetic coil actuator is stopped like the experimental example shown in Fig.7.

[0031] In cases where the aforementioned electromagnetic coil actuator and the apparatus for determining faults of an electromagnetic coil actuator are used in a control unit for an electromagnetic actuator for driving a member to be driven, the electromagnetic coil serves as a source of magnetomotive force for driving a magnetic member which drives a member to be driven. In this case, the electromagnetic coil actuator controls current supplied to the electromagnetic coil and, on the other hand, the apparatus for determining faults of an electromagnetic coil actuator determines a fault of the electromagnetic coil actuator, thereby enables to provide an increased reliability of the electromagnetic actuator.

[0032] Furthermore, to provide further increased reliability of the electromagnetic actuator, even in a unit configured such that two electromagnetic coil actuators are provided in an electromagnetic actuator, the apparatus for determining faults of an electromagnetic coil actuator, according to the present invention, may be provided in the electromagnetic coil actuators, respectively. When it has been distinguished that one of the electromagnetic coil actuators is at fault, such configuration allows the other electromagnetic coil actuator to drive the electromagnetic actuator, thereby allowing the cost to be significantly reduced compared with the case of providing a conventional apparatus for determining faults of an electromagnetic coil actuator to the two respective electromagnetic coil actuators.

[0033] In the aforementioned embodiment, an adding means comprising two resistors 3 and 5 was shown, however, it is obvious that an analog adding circuit such as an operational amplification element is used as an adding means.

Industrial Applicability

[0034] As explained above, the apparatus for determining faults of an electromagnetic coil actuator, according to the present invention, is configured so as to allow for reducing the cost and the number of resistors that are sources of heat generation to prevent an increase in temperature of the semiconductor devices. This allows for supplying current appropriately to the power supply coils and desirably determining a fault of the electromagnetic coil actuator.

Claims

1. An apparatus for determining faults of an electromagnetic coil actuator having two current paths each of which comprises a pair of switches connected in series to each other, an electromagnetic coil connected in between connection points of each pair of said pair of switches, a drive circuit for selectively driving said switches, and power supply means for applying voltage to both ends of said both current paths via a power supply line and ground line, which comprises:

   voltage detecting means for detecting an electric potential at respective connection points of said pair and for generating a first voltage signal and a second voltage signal according to said electric potential;
   adding means for generating a summing voltage signal according to a value obtained by adding a value of said first voltage signal to a value of said second voltage signal; and
   faults determining means for determining faults of said electromagnetic coil actuator based on operational conditions of said pairs of switches and the value of said summing voltage signal.

2. The apparatus for determining faults of an electromagnetic coil actuator according to claim 1, wherein said faults determining means carry out at least one of a first determining operation and a second determining operation,

   said first determining operation for determining that a supply-to-line fault has occurred because of a short circuit between said electromagnetic coil and said power supply line when the value of said summing voltage signal is greater than a first predetermined value in a condition of no power supply to said electromagnetic coil with at least one of said pairs of switches being held open and said second determining operation for determining that a line-to-ground fault has occurred because of a short circuit between said electromagnetic coil and said ground line when the difference

between the value of said summing voltage signal and the value of a power supply voltage is greater than a second predetermined value in a condition of power being supplied to said electromagnetic coil with at least one of said pairs of switches being connected.

3. The apparatus for determining faults of an electromagnetic coil actuator according to claim 1, wherein said adding means divide said first voltage signal and second voltage signal into said summing voltage signal.

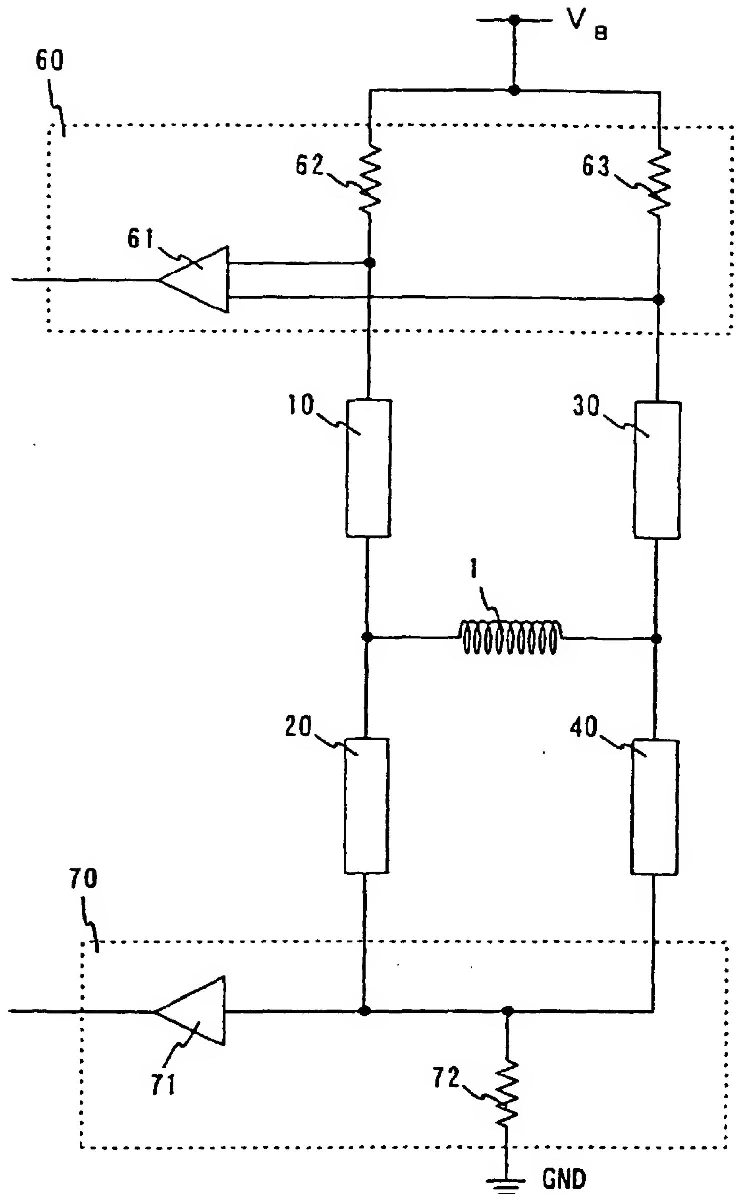
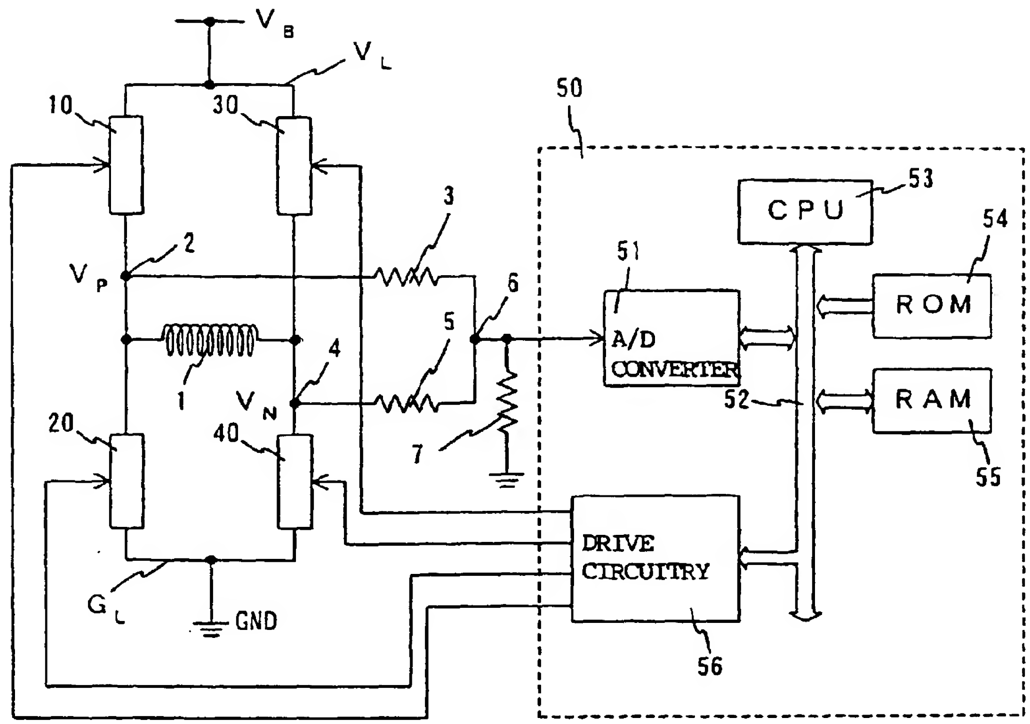


FIG. 1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V L
10
30
50
53
CPU
54
3
2
V P
51
ROM
6
A/D
CONVERTER
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4
1
V N
52
RAM
20
40
7
55
DRIVE
CIRCUITRY
G L
GND
56

FIG. 2

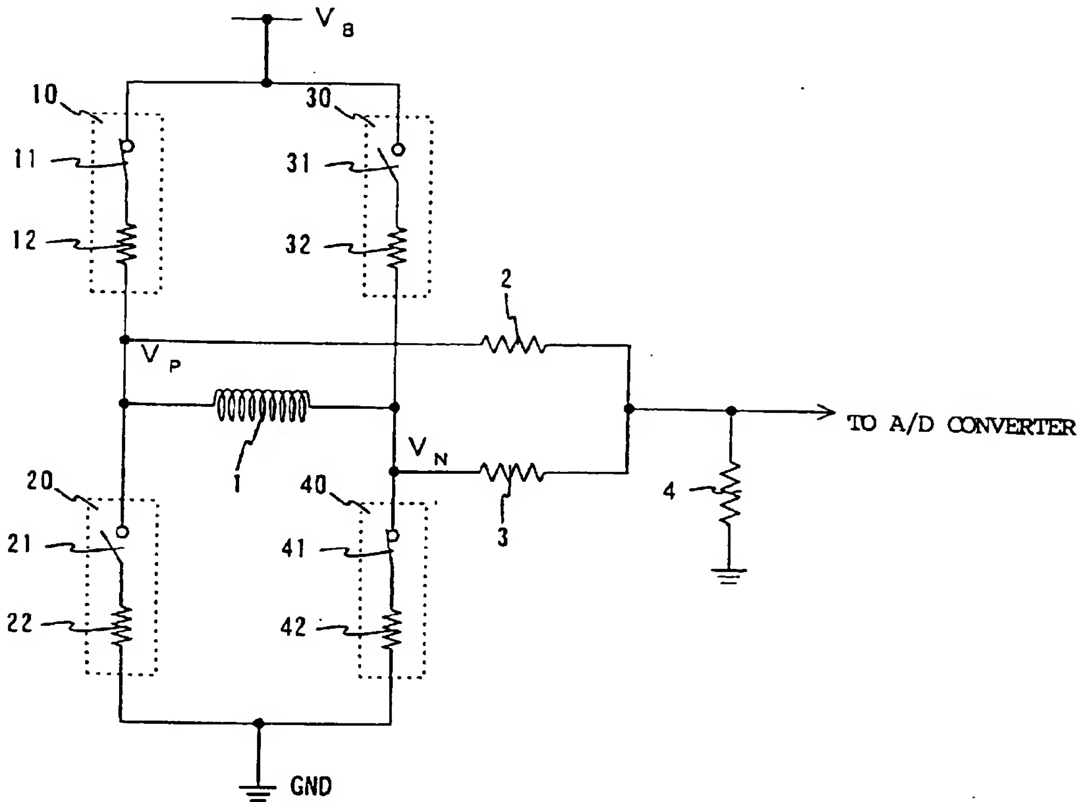
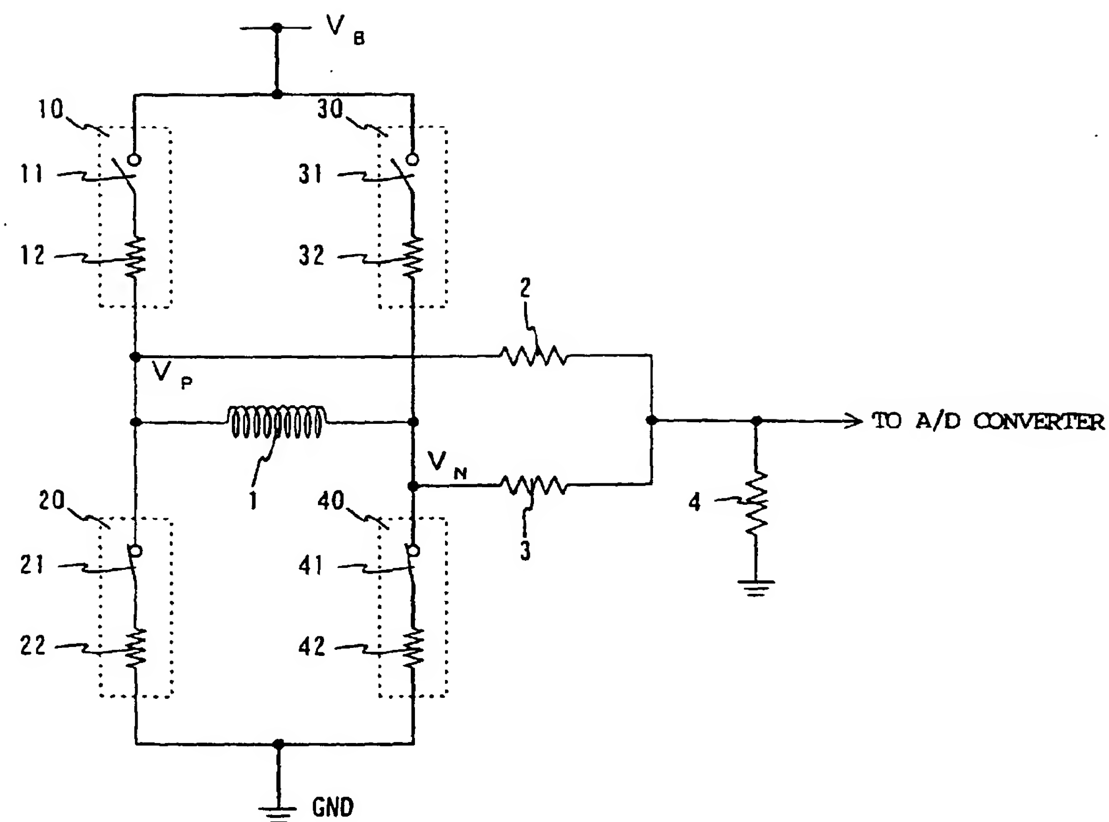

V B
10
11
12
30
31
32
2
V P
1
V N
3
4
TO A/D CONVERTER
20
21
22
40
41
42
GND

FIG.3


V B
10
30
11
31
12
32
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V P
TO A/D CONVERTER
V N
1
20
40
4
3
21
41
22
42
GND

FIG. 4

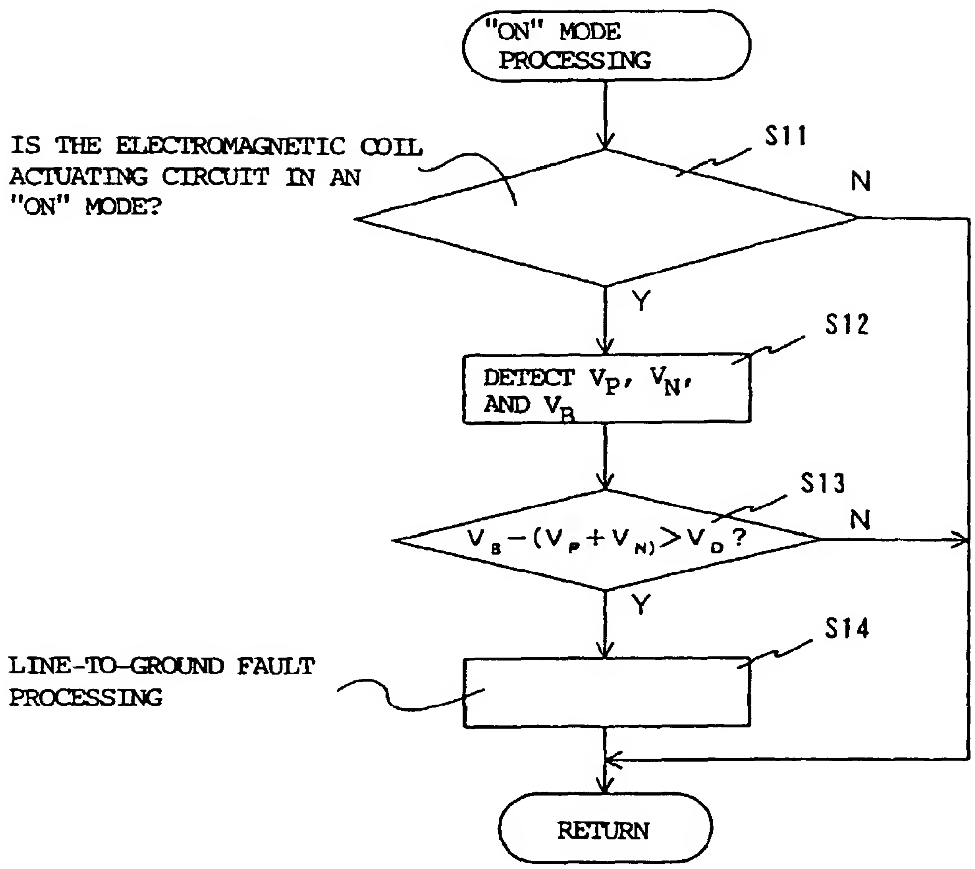
"ON" MODE PROCESSING
IS THE ELECTROMAGNETIC COIL ACTUATING CIRCUIT IN AN "ON" MODE?
S11
N
Y
DETECT V_P, V_N, AND V_B
S12
S13
$V_B-(V_P+V_N)>V_D$?
N
Y
S14
LINE-TO-GROUND FAULT PROCESSING
RETURN

FIG. 5

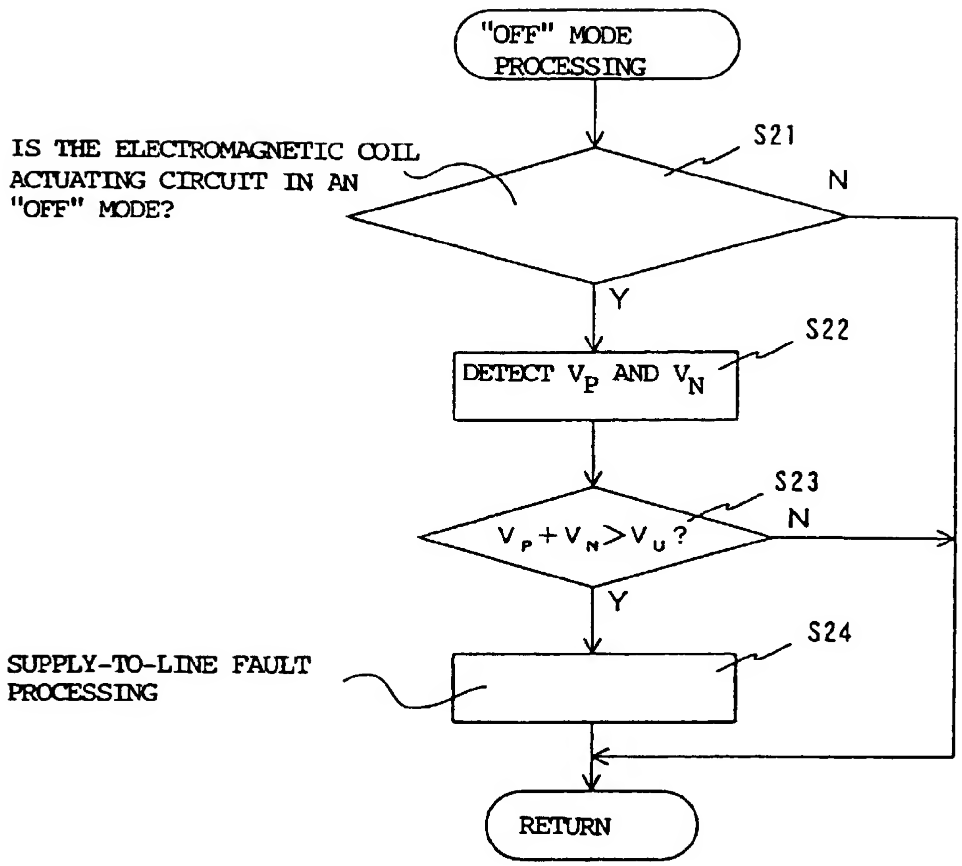
"OFF" MODE PROCESSING
IS THE ELECTROMAGNETIC COIL ACTUATING CIRCUIT IN AN "OFF" MODE?
S21
N
Y
DETECT V_P AND V_N
S22
$V_P + V_N > V_U$?
S23
N
Y
SUPPLY-TO-LINE FAULT PROCESSING
S24
RETURN

FIG. 6

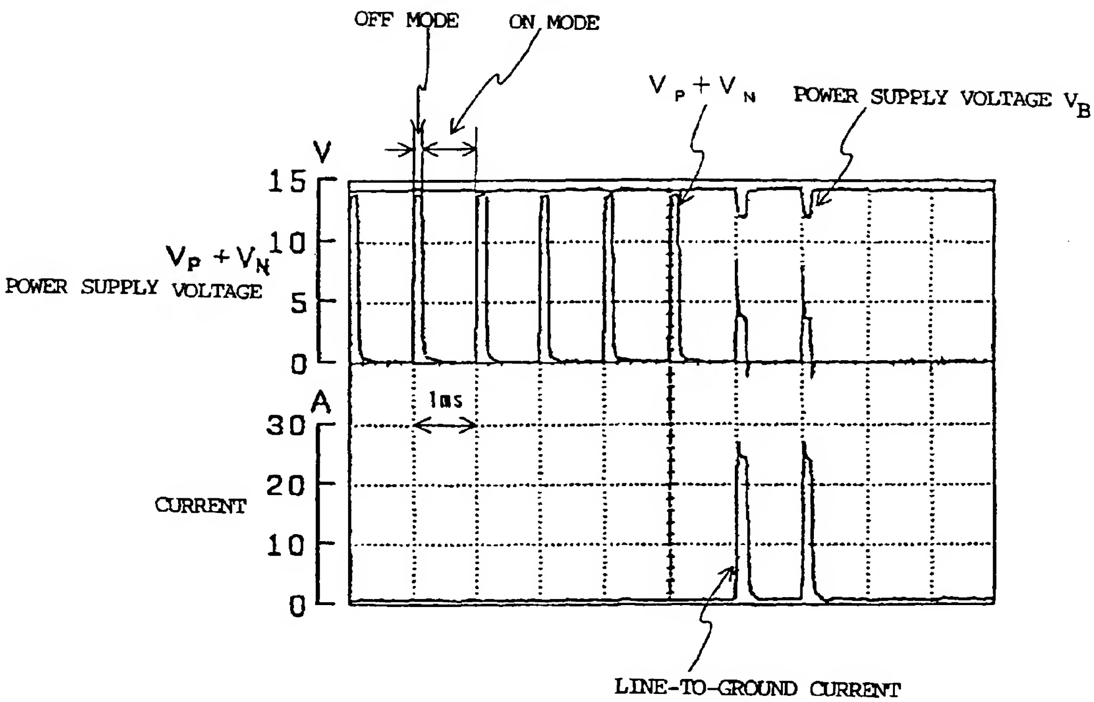
OFF MODE
ON MODE
V_P+V_N
POWER SUPPLY VOLTAGE V_B
V
15
10
5
0
V_P+V_N
POWER SUPPLY VOLTAGE
A
30
20
10
0
1ms
CURRENT
LINE-TO-GROUND CURRENT

FIG.7

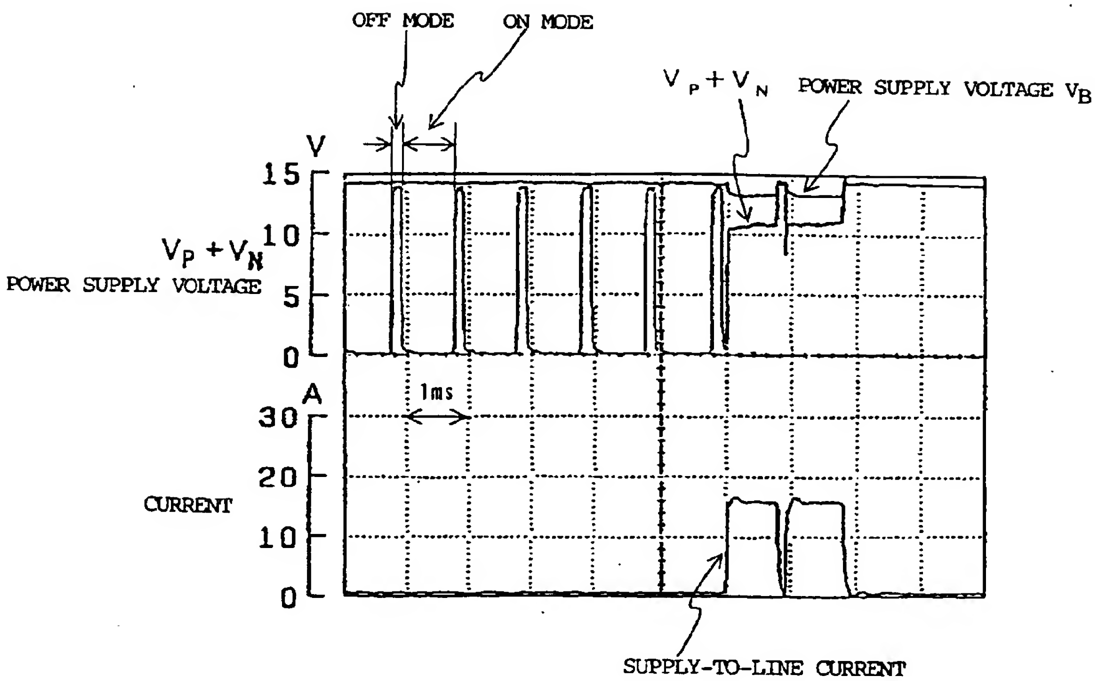
OFF MODE
ON MODE
$V_P + V_N$
POWER SUPPLY VOLTAGE V_B
V
15
10
5
0
$V_P + V_N$
POWER SUPPLY VOLTAGE
A
1ms
30
20
10
0
CURRENT
SUPPLY-TO-LINE CURRENT

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP99/01753

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl6 G01R31/02, H01F7/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl6 G01R31/00, 31/02, H01F7/20

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1940-1996	Toroku Jitsuyo Shinan Koho	1994-1999
Kokai Jitsuyo Shinan Koho	1971-1999	Jitsuyo Shinan Toroku Koho	1996-1999

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP, 5-185937, A (Omron Corp.), 27 July, 1993 (27. 07. 93), Par. Nos. [0030] to [0036], [0050] to [0053] ; Figs. 1 to 6, 14 (Family: none)	1-3
A	JP, 7-46885, A (Nippon Carbureter Co., Ltd.), 14 February, 1995 (14. 02. 95), Full text ; Fig. 1 (Family: none)	1-3
A	JP, 4-238272, A (Nihon Inter Electronics Corp.), 26 August, 1992 (26. 08. 92), Full text ; Figs. 1, 2 (Family: none)	1-3

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 June, 1999 (17. 06. 99)	29 June, 1999 (29. 06. 99)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)